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Reticle Color Preference as a Function of Background and Luminance

by

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Weapons Development Department

JANUARY 1974

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W. J. Moran, RADM, USN . . . . Commander
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FOREWORD

The Naval Air Systems Command is sponsoring the advanced development of a new short-range air-to-air missile system at the Naval Weapons Center (NWC), China Lake, Calif. This system, identified as Agile (Task Assignment A-30303/216-1/W16-25000), is specifically designed for visual short-range engagements. Human factors analyses are part of the effort being made toward the development of the Agile missile system. This study investigates the preference of pilots for various reticle colors that could be used in the helmet-mounted sight unit.

This report has been reviewed for technical accuracy by F. E. Nicodemus and H. P. Leet. It is released at the working level for information only.

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20 December 1973

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See back of form.

(U) *Reticle Color Preference as a Function of Background and Luminance*, by Jeffrey D. Grossman. China Lake, Calif., Naval Weapons Center, January 1974. 16 pp. (NWC TP 5610, publication UNCLASSIFIED.)

(U) The relative preference for six different reticle colors was determined under three conditions: (1) high level, varying luminance, (2) low level, varying luminance, and (3) high level, equal luminance. All colors in each condition were presented by the method of paired comparisons. The results indicated that in the first two conditions, green, orange, and yellow were almost equally preferred. In the third condition, green was most preferred. Background was not a significant factor in reticle color preference.

CONTENTS

INTRODUCTION

Currently under development at the Naval Weapons Center, China Lake, Calif., is the Agile missile system which will incorporate a seeker that is capable of locking on targets at large off-boresight angles. An integral part of the Agile concept is the electronic coupling of the seeker with the aircrewman's helmet. When the helmet is pointed at the target, its position is made known to the seeker via the Visual Target Acquisition System (VTAS). The seeker then slews to the angular position of the helmet. The aircrewman's eyes are aligned to the helmet by means of a helmet-mounted sight which is aligned with the VTAS at known angles.

Several candidate configurations are either available or being developed to implement the helmet-mounted sight (HMS) unit of the VTAS. Several of these approaches may be disadvantageous in at least one respect; they are available with a limited choice of HMS reticle colors. The effect of the color of the reticle on performance of the air superiority mission is unknown. In fact, reticle color has never been a real consideration in the design of a sight system as far as can be determined. One study that may be relevant to the problem was conducted by the U.S. Air Force. Hilgendorf[1] studied detection and identification performance using colored lights against various backgrounds. His data indicated that performance was very good with a green stimulus except when the background was also green. In his study, however, he used a green background with a dominant wavelength in the 550-mμ region of the spectrum. Penndorf[2] has determined that natural objects (forests, meadows, bare soil, etc.) have average dominant wavelengths in the 570- to 590-mμ range, which is relatively yellowish-green. Presumably, as measured by Hilgendorf, a greater difference in color between the green hue of the stimulus and the green-yellow hue of the background would improve performance.

In a later experiment, Reynolds, White, and Hilgendorf[3] again measured the speed of detection and accuracy of identification of four

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[1] Hilgendorf, Robert L. "Optimal Colors for Markers and Signals," in *Proceedings of the Seventh National Flight Safety, Survival and Personal Equipment Symposium*, Vol. 1, 21-30 October 1969, Las Vegas, Nev.

[2] Penndorf, Rudolf. "Colors of Natural Objects," OPT SOC AMER, J, Vol. 46, No. 3 (March 1959), pp. 180-182.

[3] Reynolds, R.E., R. M. White, and R. L. Hilgendorf. "Detection and Recognition of Colored Signal Lights," *Human Factors*, Vol. 14, No. 3 (June 1972), pp. 227-236.

colored lights against four colored backgrounds. It was found that the ordering of stimulus colors as measured by the speed of responding, from fastest to slowest, was red, green, yellow, and white. For errors in color naming, the order, from least to most, was green, red, white, and yellow. It was noted that in choosing the most effective signal color in a specific situation, background color, background brightness, and the amount of ambient illumination must be taken into consideration.

It would have been preferable to measure the performance of pilots using different colored HMS reticles. However, a test that would provide meaningful performance data could not be devised using the available resources.

Besides performance, an important consideration in the choice of a reticle color is the response of the aircrewman to the choice. With the possibility that the HMS design will dictate the requirement for a specific color, some question has arisen about whether aircrewmen would find certain colors acceptable. This study responds to that question by allowing pilots to study six reticle colors that could conceivably be used in the HMS, and to indicate their preference for them. The objectives of this study were to: (1) determine the relative preference for the six colors, (2) determine the effect of background on preference, and (3) make these determinations under varying conditions of luminance.

METHOD

EXPERIMENTAL DESIGN

Two reticle characteristics were controlled--luminance and color. Luminance is a phenomenon that relates the radiant energy of a light source to the spectral sensitivity of the standard human eye. For example, if the radiant energy from two sources of light were equal, but one appeared blue and the other green, the green light would be more luminant since the eye is much more sensitive to wavelengths in the green region of the spectrum. However, if the energy sources were adjusted to account for the differences in the eye sensitivity to the wavelengths of the colors presented, the lights would be equally luminant.

The experiment was divided into three phases. In Phases I and II, the radiometric energy of the light sources was equal so that the reticle colors had the same luminance relationship as they have on the standard eye spectral efficiency curve (see Figure 1). In other words, the luminance of the colors was not equal. In Phase I the reticles were made to appear very bright; in Phase II they were made to appear dim. In Phase III the reticle colors were of equal luminance and were easily visible.

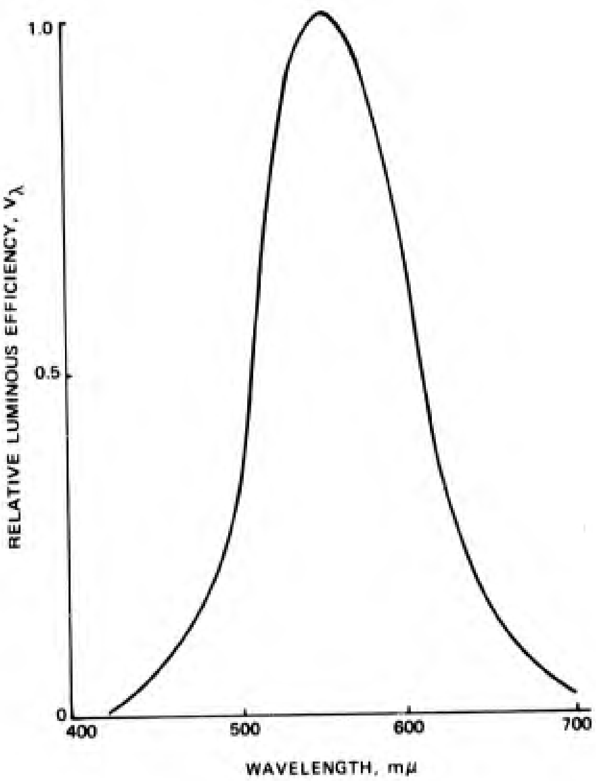

FIGURE 1. The Photopic Luminous Efficiency Curve Reported by Commission Internationale de l'Eclairage (C.I.E.).[4]

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[4] Le Grand, Yves. *Light, Color, and Vision*. London, Chapman, and Hall, Ltd. 1968. P. 124.

A third variable in this experiment was background. Each of the six reticle colors was viewed against three different colored backgrounds--blue, green, and white.

In each of the three phases, the method of paired comparisons was used. By this method,[5] all of the reticle colors were eventually paired in all possible combinations except identical color pairs. In this way, they overlaid the test background visible through the glass. Each color in each pair was seen with its partner on both its left and right sides. The order in which the pairs were presented was randomized for each phase and background of the experiment. The order in which the backgrounds were presented was counterbalanced; each subject was randomly assigned to and participated in only one phase.

The subject's task was to compare the colored reticles of each pair and to choose the one he most preferred. By comparing each stimulus with every other one, each one became a standard for the other. Equality judgments were not permitted since all the subjects observed each pair twice and a judgment of equality would have been indicated by an inconsistency in the two choices. When all pairs were presented to all the subjects, the reticle colors were ranked according to the frequency with which they were preferred.

SUBJECTS

The subjects consisted of 18 naval aviators ranging from Lieutenants (j.g.) to Commanders. All were pilots of high-performance combat aircraft. Flight experience ranged from 425 to 5,200 hours flight time, including zero to 150 combat missions. Most of these subjects had experience primarily with off-white reticles that were produced by an incandescent source.

APPARATUS

In this experiment, the light sources used to illuminate the reticles were Kodak Carousel 600 Series slide projectors with 500-watt projection lamps. The reticles were projected through half-silvered combining glasses using two identical Douglas Librascope gunsights. These were slightly modified by removing the first diffusing lens in each one and replacing it with a flat ground glass. (The diffusing lens that was removed focused a diffused spot of light onto the combining glass but with an area smaller than that of the reticle. The ground glass that replaced it diffused the light over the entire reticle area.) The reticle in each gunsight was replaced with microscopically measured reticles to insure they were both identical. A diagram of the reticle display is shown in Figure 2.

[5] Guilford, J. P. *Psychometric Methods*. New York, McGraw-Hill, 1936. Pp. 217-220.

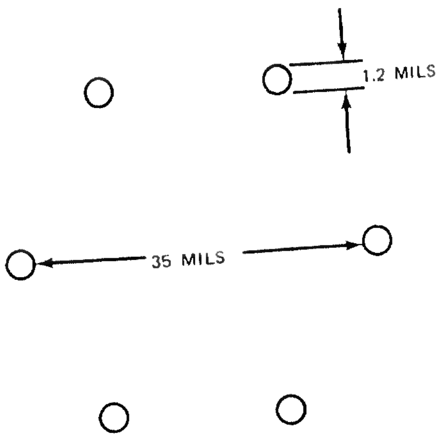

FIGURE 2. Enlarged View of Experimental Reticle Design. The reticles were colored dots on the combining glasses of the gunsights.

Attached to each gunsight at the light-receiving end was an adjustable iris for controlling the amount of light that entered the gunsight and hence the observed luminance. Between each gunsight and its light source was a filter holder which could hold three filters. One precaution taken against the heat of the projection lamps was the incorporation of a fan that increased the airflow around the filters. A flat black simulated helmet, designed to reduce the ambient glare around the subject's eyes, covered the gunsights and combining glasses. The front of the helmet shell contained a standard, tinted, Plexiglass Navy helmet visor. This arrangement is shown in Figures 3 and 4.

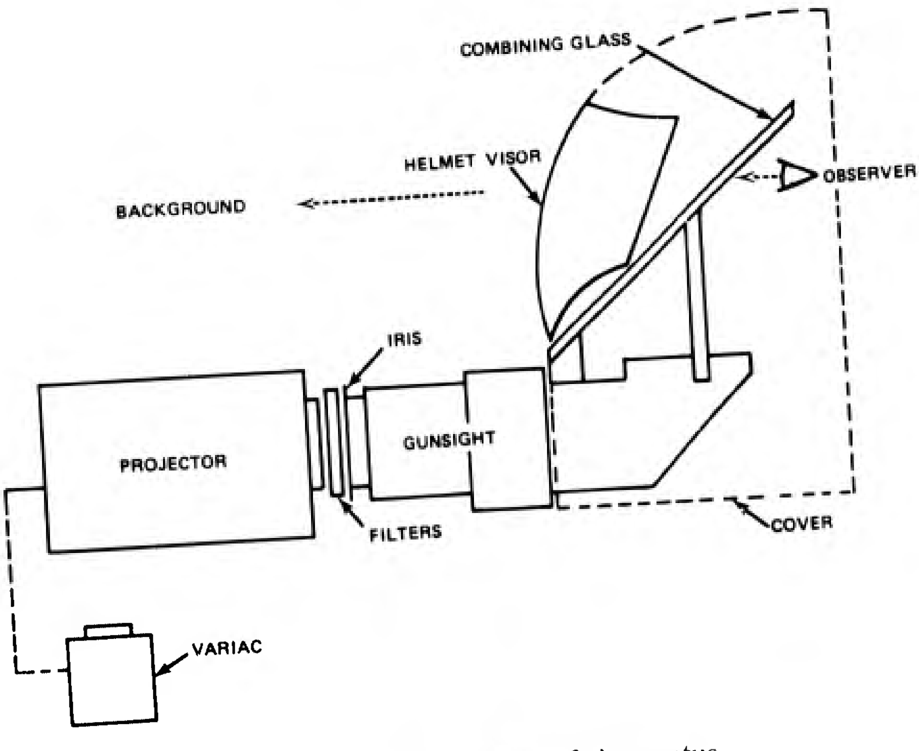

FIGURE 3. Side View of Apparatus.

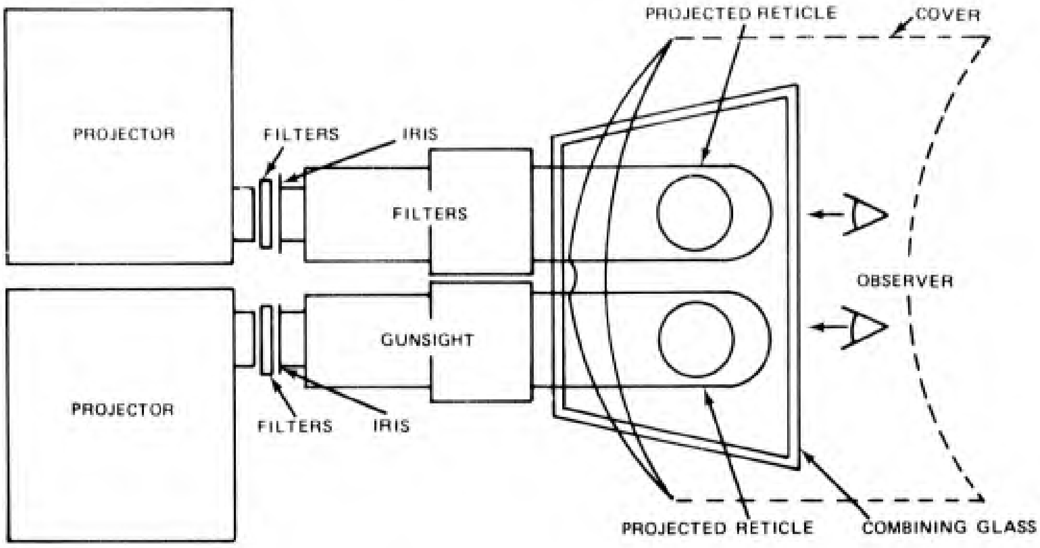

FIGURE 4. Top View of Apparatus.

The filters used to obtain colored reticles were narrow bandpass interference filters manufactured by Optics Technology, Inc. Each filter was imbedded in 2- by 2-inch glass plates. The nominal wavelengths of the six colors were:

Blue	486 mμ
Green	520 mμ
Yellow	579 mμ
Orange	589 mμ
Red	656 mμ
White, nominal optical neutral density	1.0

These interference filters were placed in the filter holder in the slot farthest from the light source to minimize the danger of discoloration by the heat of the projection lamp. A clear heat absorbing glass was placed in the slot closest to the heat source as additional protection for the filter. The middle slot of the filter holder was used to hold a 0.5-neutral-density filter during the second phase of the experiment. This filter reduced the amount of light reaching the eye in the second phase by 68% and made the colors subjectively barely visible. The apparatus was adjusted and checked for the equality of color temperature and luminance at the light sources. Color temperature was equated by adjusting the input voltage to the projection lamps with a Variac while measuring the output with an optical pyrometer. The color temperature was determined to be 2700°K. When the color temperatures were equated, the luminances of the two lamp filaments were measured with a Spectra Brightness Photo Spotmeter to insure they were equal.

The three backgrounds used in the experiment were: (1) a blue sky, approximately 40 deg above the horizon; (2) a patch of grass that was recovering from the winter frost and was thus streaked with light browns against a predominantly green field; and (3) a white, corrugated steel quonset hut simulating clouds. The tests were run in the afternoon when the sun was in the western half of the sky. The observer looked to the east to observe the reticle against the blue sky, the bright white building, and the grass backgrounds.

In Phases I and II, where the six reticle colors were to have the same luminosity relationship they would have under conditions of equal energy, the amount of energy had to be varied to account for the different densities of the colored filters used. The radiance variation, which was achieved by using the adjustable iris, was determined by integrating the product of the lamp spectral radiance and filter spectral transmission curves (Eq. 1).

$$L_{e,i} \text{ (radiance)} = \int_o^\infty L_{e}\lambda\ (\lambda)\cdot\tau_f\ (\lambda)\cdot d\lambda \tag{1}$$

The integral, or radiance, was used in Eq. 2 to determine the aperture size (A) for each reticle color.

$$A = \frac{C_1}{L_{e,i}} \tag{2}$$

where

C_1 = constant.

In Phase III, where the reticle colors were of equal luminance, the energy variation was determined by multiplying the lamp spectral radiance curve and the curve of the spectral response of the standard eye (Figure 1), and multiplying that product by each of the six filter spectral transmission curves (Eq. 3).

$$L_{v,i} \text{ (luminance)} = \int_o^\infty L_{e\lambda}\ (\lambda)\cdot\tau_f(\lambda)\cdot K\ (\lambda)\cdot d\lambda \tag{3}$$

The integral of the second product, the luminance, was used in Eq. 4 to determine the aperture size (A) for each equally luminous reticle color.

$$A = \frac{C_2}{L_{v,i}} \tag{4}$$

where

C_2 = constant.

To insure that the six colors were of equal luminance, a Photo Spotmeter reading of the luminance of the reticles was taken.

PROCEDURE

The subjects were tested individually. Each subject was seated in front of the apparatus and given instructions. The subject was then shown 30 randomized sets of reticle pairs, all of which were viewed against the same background. The task of the subject was to choose one reticle of the pair that he most preferred on the basis, in his judgment, that it was more visible, more distinct, and easier to see. After completing the first set, the apparatus was rearranged to face a different background and the subject was shown the same 30 pairs in a different random order. This procedure was repeated for the third background.

RESULTS

COMPARISON OF ALL COLORS

A chi-square analysis was performed, which indicated that the three backgrounds had no effect on reticle color preference ($\chi^2 = 6.83$).

The data shown in Figure 5 indicate that the preferences followed the spectral efficiency curve for the eye in Phases I and II. White, blue, yellow, orange, and red were, for all practical purposes, equally preferred in Phase III. This is as would be expected since the luminances were equated. Green, however, was preferred more often than the other colors in Phase III.

The reticle colors were ranked by frequency of selection, and Friedman's "Two-Way Analysis of Variance by Ranks"[6] was used to test the hypothesis that the rank of a particular color was not due to chance. In each of the three phases the results indicated that we could be 95% confident that the rank orderings were not due to chance. In Phase I, the yellow and orange reticles were ranked higher (more preferred) than all other colors (95% confidence level); however, they were not ranked significantly different from each other. In Phase II, green and orange were ranked higher (99% confidence level) than all other colors, but were not ranked significantly different from each other. In Phase III, green was ranked higher (99% confidence level) than all other colors.

If the results of the three phases are combined, green, yellow, and orange remain the favored candidates. A detailed analysis of the data from just the green-yellow-orange comparisons was made to aid in deciding among these three.

COMPARISON OF GREEN, YELLOW, ORANGE

The data as shown in Table 1 are combined for all pilots. It can be seen that most comparisons showed an equal preference for the two colors compared. Only two comparisons show unequal preferences: orange was preferred to green when seen against the blue sky, and orange was preferred to yellow when seen against green foliage. For all but these two comparisons, the type of background did not affect preference. All else being equal, orange would be recommended from the Phase I results.

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[6] Sears, Francis W. *Optics*. Cambridge, Addison-Wesley Press, 1949. P. 337.

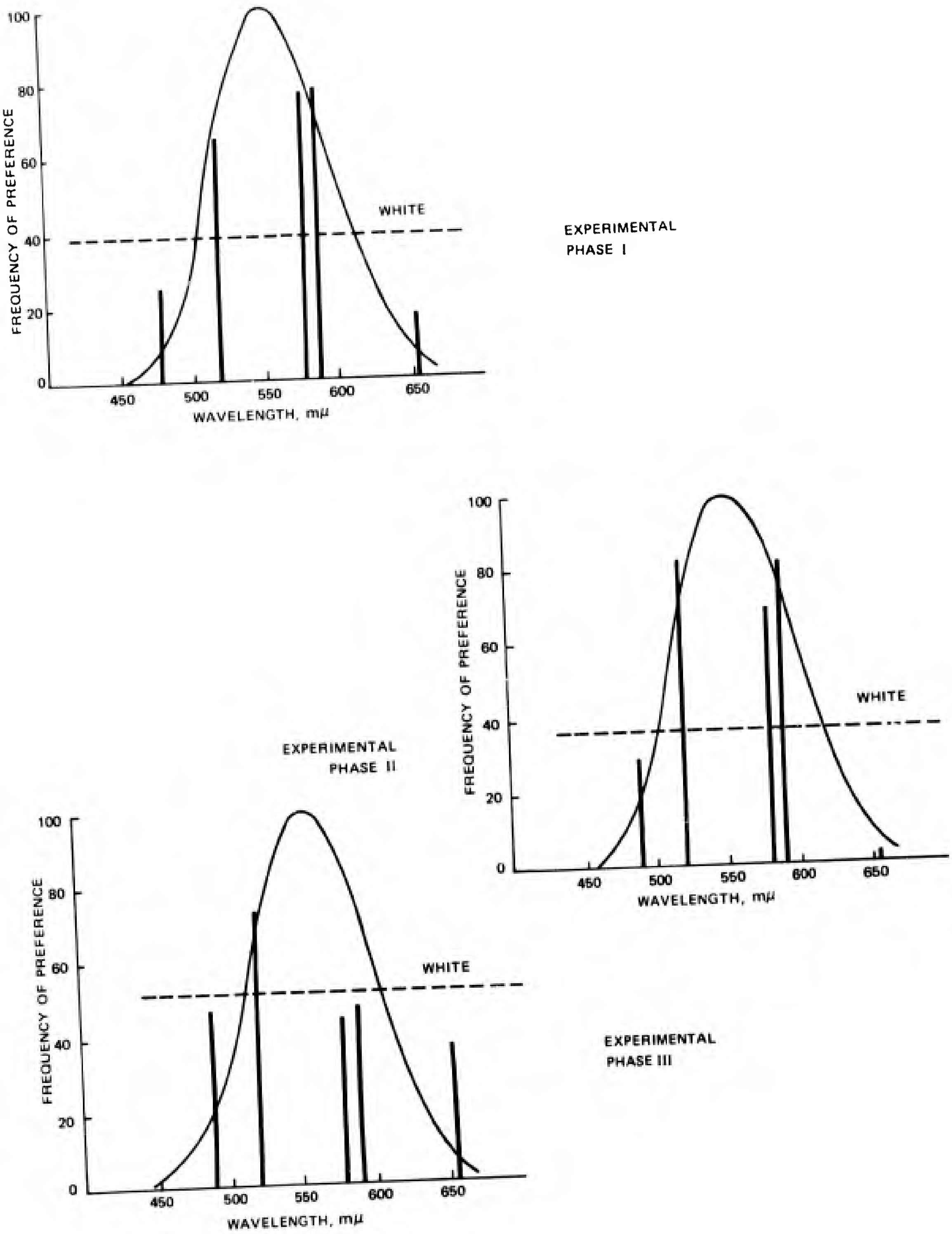

FIGURE 5. Frequency of Color Choice Plotted With Spectral Efficiency Curve for Standard Observer for 2-Deg Field. Data obtained under experimental Phases I, II, and III.

TABLE 1. Number of Times Each Color was Preferred in Phase I.

Pairs of colors compared	Background		
	Blue sky	White	Green foliage
Yellow	6	5	6
Green	6	7	6
Yellow	7	6	4
Orange	5	6	8
Green	4	6	6
Orange	8	6	6

The Phase II results are shown in Table 2. For blue sky and white backgrounds, orange is preferred to yellow, but green is preferred to both yellow and orange. The orange-over-yellow preference is still evident for the green background, but green is no longer preferred more often than yellow or orange. If the results are combined across backgrounds, green is the preferred color, with yellow being the least preferred.

TABLE 2. Number of Times Each Color was Preferred in Phase II.

Pairs of colors compared	Background		
	Blue sky	White	Green foliage
Yellow	4	2	6
Green	8	10	6
Yellow	3	1	3
Orange	9	11	9
Green	8	9	6
Orange	4	3	6

The Phase III results are shown in Table 3. Green was preferred to both orange and yellow for the blue sky and white backgrounds. Green was preferred to orange when viewed against the green foliage background. The only other preference was orange over yellow for the blue sky background.

TABLE 3. Number of Times Each Color was Preferred in Phase III.

Pairs of colors compared	Background: Blue sky	White	Green foliage
Yellow	4	2	5
Green	8	10	7
Yellow	3	5	5
Orange	9	7	7
Green	10	9	10
Orange	2	3	2

The preferences discussed above are summarized in Table 4. The only systematic background effect was the absence of a preference for green when viewed against the green background. That is, green was preferred over orange and yellow against the blue sky and white backgrounds, but was no better than the others for the green background.

TABLE 4. Reticle Color Preference for Phases I, II, and III.

Phase	Preference	Background
I	Orange over green Orange over yellow	Blue sky Green
II	Green over yellow	Blue sky White
	Green over orange	Blue sky White
	Orange over yellow	Blue sky White Green
III	Green over yellow	Blue sky White
	Green over orange	Blue sky White Green
	Orange over yellow	Blue sky

SUMMARY

There was no strong color preference under the Phase I conditions. If the HMS design is such that the reticle can be made very bright, regardless of color, color choice could be dictated by engineering considerations.

If power is limited, so that brightness might be marginal (Phase II), green would be the preferred color. When colors of equal luminances were compared (Phase III), green was also preferred. This latter preference was not related to differences in color brightness, which was probably the case in Phases I and II; it was more likely a clear indication of real preferences. Since the pilots normally used a white reticle, the preference for green was probably not a reflection of familiarity.

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